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ABSTRACT

As six subjects read a history text, their eye movements/fixations were monitored and recorded. A processing profile was created for each subject, and the correlations between pairs of profiles were computed. The correlations were all positive, but quite small. Although the differences between correlations were not large enough to indicate a definite rank order, one generalization emerged: the higher correlations were associated with processing spans shorter than or equal to the saccade length. This finding tends to support the idea that the perceptual span extends from one fixation point rightward to the point of the next fixation. In the production of a single profile that represented the processing load at various points in the text, it was observed that less attention/fixation was given to the definite article "the," and that increased processing times occurred for dates and numbers in the text. Since many issues concerning the reading process are critically dependent upon notions of processing load, the construction and analysis of processing profiles from eye movement records can be quite useful to reading researchers and theorists. (RL)

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Time on Text: The Use of Eye Movement Records in Assigning Processing Time to Text

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CS005322

This afternoon I would like to talk about two problems. The original problem I set out to investigate concerned the role of lexical ambiguity in natural language. I wanted to know how words that, in isolation, could have several distinct meanings were processed when encountered in normal text. The use of eye movement records seemed like an elegant way to measure the effects of ambiguity. After collecting eye movement records from subjects reading passages containing ambiguous words, however, the second problem presented itself. How should the eye movement records be used to draw inferences about processing time for ambiguous words or, in general, how should these records be used to assign processing time to the text being read?

Natural language ambiguities have interested psychologists for many years. Lashley's (1951) garden path sentences provide an example of the types of difficulties ambiguity can lead to. Normally, however, potential sources of ambiguity are not consciously detected and potential meaning indeterminacies is quickly resolved.

A number of recent investigations have addressed the question of whether encountering an ambiguous word prompts the retrieval of all meanings of the word or only the single contextually appropriate meaning. Unfortunately, the results from a number of studies do not converge on a single answer to this question. Different measurement tasks seem to yield different results. Recognition and recall tasks tend to support a single meaning hypothesis (Jenkins, 1977). Phoneme monitoring reaction times tend to support the hypothesis that all meanings are evaluated (Foss & Jenkins, 1973). Using an ambiguity detection task I have found support for the

suggestion that the most common meaning of an ambiguous word (primary sense) is evaluated first, regardless of context and only when primary meanings are inappropriate are other meanings evaluated (Hogaboam, 1978; Hogaboam & Perfetti, 1975).

The question is how to make sense out of these seemingly discrepant findings. Jack Yates (1979) has recently suggested that a two stage lexical access model such as that proposed by Posner and Snyder (1975) may account for a number of discrepant results. By invoking certain assumptions about which tasks are tapping which stage of lexical access, Yates builds an argument for characterizing the first stage as activating all meanings of an ambiguous word. The second stage then evaluates primary meanings first to determine if they are contextually appropriate.

The problem, of course, is determining, on the basis of independent evidence, which tasks are sensitive to which stage of lexical access. The present study was initiated with the hope that eye movement records would provide some indication of how ambiguous words were processed. The thought was that by using eye movement records many of the measurement problems associated with the use of secondary tasks would be avoided. Eight subjects each read eight passages while their eye movements were recorded. An example of the materials is presented in Table 1, page 10b. These passages were constructed to implement several variables. Today I would like to focus on only one of these, primary sense usage vs. secondary sense usage. In these passages, the fourth sentence was identical in both the primary sense and secondary sense passages and contained the ambiguous word of interest, in this case the word "letter." The disambiguating context was

the preceeding sentences and, of course, was different for the primary and secondary sense passages. Previous studies (Hogaboam & Perfetti, 1975; Yates, 1978) had found that longer processing times are associated with secondary senses. The question was would this effect show up in eye movement records or was it simply an artifact of the secondary tasks that had previously been employed.

After collecting the data, however, it immediately became apparent that I had underestimated the complexity of eye movement records. I didn't know where to look in these records for evidence of processing time differences between primary and secondary senses. The problem was the unknown relationship between cognitive processes and eye movement control. Not knowing the general nature of eye movement control it is difficult to know what is being measured by various aspects of eye movement data. One approach is to explore various aspects of the eye movement records to discover a measure which yields a significant difference. In this spirit, I looked at fixations that were located on the ambiguous word and found that the average fixation times on secondary senses were significantly longer than on primary senses. Also, there were more regressions to secondary senses, but this was not significant. This is prima facie evidence that secondary senses take longer to process but there are problems with this interpretation.

One problem is that subjects simply do not always look at the places in the text where you have so carefully implemented your independent variable. This leads to unequal n's and unbalanced designs. Presumably, however, this does not mean that they have not read that part of the text. Somewhere in the records there should be effects of ambiguity even if they do not fixate

the ambiguous word. There are two other problems that are particularly bothersome; 1) the eye-mind lag and 2) the perceptual span. Suppose that the eyes are controlled by a system that simply puts information in a buffer. This would allow the eyes to be picking up visual information some distance ahead of what the mind is interpreting. If this is the case, however, where should one look in the eye movement records for evidence of ambiguity effects? If the eye movements are affected at all, the effects would only show up when the eye is several fixations farther down the line when the mind has finally reached the ambiguity.

Finding effects of ambiguity, as I did, for fixations occuring <u>on</u> the word would seem to indicate that either the eye-mind lag is small and eye movements are under rather immediate cognitive control, or that the effects I have attributed to ambiguity are really due to something occuring earlier in the text.

Even if it is assumed that the eye-mind lag is small or non-existant the problem of perceptual span remains. McConkie and Rayner have suggested that the span may extend 4 character positions to the left and perhaps 8 characters to the right of the fixation point. If I am interested in the processing time due to one particular six letter word, the fixation duration of any or all fixations occuring in a 19 character position area may be of interest, but which one or ones should be chosen?

One approach is simply to average all fixations in a large area that includes the variable of interest. The problem here is that if a word is only read on a single or perhaps two fixations the effects of that word will be diluted. In short, it is not at all obvious how to use eye movement

records to draw inferences about processing time attributable to specific areas of the text.

I would like to present one rather general method for using eye movement records to assign processing time to texts. This approach will not answer the questions posed above, but it will, hopefully, provide a framework for thinking about possible answers.

Consider Figure 1 on page 11 of your handout. The wavy line represents a hypothetical processing profile where the average height of the profile over any given segment of text represents the amount of processing time attributable to that segment during normal reading. There are a number of assumptions implicit in proposing that such a profile can characterize the processing time of a text. I will not attempt to address these now, but many of these assumptions are common to other reaction time measures. For now, I will simply assume that there is a real underlying processing profile that characterizes text in normal reading situations. The question is, can the underlying profile be recovered from eye movement records?

Consider Figure 2, Panel A, on page 12 of your hand-out which presents an idealized sample of eye movement data. The first fixation, for instance was on the word "people" and lasted 238 msec. Consider the fifth fixation, which lasted 250 msec. Presumably this time was spent processing some region of the text. I would like to call this region the processing span and distinguish it from the perceptual span. The processing span is that area of text to which we can attribute the fixation duration of each fixation. This may or may not be the same as the perceptual span. Let us assume, for the moment, that this region is the same as the perceptual span and, further,

that it extends from the point of fixation to a point 1 character short of the next fixation, the sixth, as suggested by McConkie (1978). If that 250 msec. is due to the processing of these 10 positions we can spread the total time out evenly and assign 25 msec. of processing time to each position. This is illustrated in Panel B. I am not invoking a letter by letter reading assumption here. One could just as easily talk about spreading the time over so many minutes of arc. The only assertion here is that the fixation time should be spread out evenly over a certain amount of space. This assumption can later be relaxed.

If this procedure is followed for each fixation a processing profile is generated as in Figure 2, Panel C. For each subject then, a certain amount of processing time can be assigned to each area of the text, greatly reducing the problem of missing data.

Suppose now that our first estimation of the processing span was wrong and that the span really extends 2 characters to the left and 5 characters to the right of each fixation point. Spreading the fixation durations out evenly under this assumption yields a different profile, as in Figure 2, Panel D. Similarly, every different proposal of what text region is being processed on each fixation will yield a different profile. How should the appropriate region be chosen?

Certainly the research on perceptual span should guide the selection but there is another approach which may also be useful. If we did know what region of text was being processed on each fixation and assigned times to each character position accordingly, then a correlation should exist between different subjects reading the same text. Consider Figure 3 on

page 13. The smooth lines represent the hypothesized processing profile. The arrows represent fixation points for two different subjects reading this segment of text. Suppose that the real processing span extends from one fixation point rightward only as far as the next fixation point, and that we know this and spread the fixation durations accordingly. The superimposed step functions represent the profile we would construct. These two profiles should correlate as we have taken the durations produced by the underlying function and spread them out evenly over exactly the right area. If we had mistakenly thought that the processing span extended from the point of fixation 10 characters to the right, the profiles would show a lower correlation.

Of course, we do not know what the appropriate span is. We can, however, construct processing profiles according to many different presumed processing spans and look for the one that leads to the highest correlation between subjects. This will hopefully be the one that most accurately captures the appropriate processing span.

To test this approach twelve subjects read a 37-line passage about the history of Alaska. Six subjects were discarded because their heads moved too much while reading. Two general classes of hypotheses about processing spans were tested: 1) fixed span hypotheses and 2) eye position dependent hypotheses. The fixed spans that were tried ranged from 1 to 13 character positions. In the eye position dependent hypotheses the span varies from fixation to fixation and is measured with reference to the location of the following fixation. Nine different spans were tried. Additionally, several methods of spreading out the fixation durations were explored, such as

subtracting 50 msec. for "cognitive overhead" before dividing by the processing span. For each of these proposed spans a profile was created for each subject and the correlations between each pair of subjects was found. Each prosed span, then, gives a six by six correlation matrix. There were several general results from this analysis. First, the correlations were all positive, but quite small. As the correlations are to be used to rank order the hypotheses about processing spans, however, the actual magnitude is not the primary concern. Overall small correlation coefficient were expected for a number of reasons. Unfortunately, the differences between the individual correlations were also not large enough to indicate a definite rank order. However, one generalization emerged. When the proposed processing span was larger than the normal saccad length the correlations were the lowest, no higher than .09 and mostly non-significant, averaging .06. When the span is shorter, correlations ranged to .15 and average .10 these were mostly significant. Thus, among these overall low correlations, the highest ones are associated with spans shorter than or equal to the saccad length. This group of spans includes the proposal by McConkie that the perceptual span extends from one fixation point rightward to the point of the next fixation. This, then, I will take as the current "best guess" about the processing span, as it is both consistent with some experimental data and with the results of the above analysis.

Using this assumed span, I went back and compared the height of their profiles over primary and secondary senses in the ambiguity study. As before, more processing time was needed for secondary senses than for primary senses. With this analysis, however, the problem of missing data was greatly reduced.

A related, but more exciting, possibility is averaging the individual profiles across subjects to produce a single profile that represents the processing load at various points in the text. Figure 4, page 14 presents an averaged profile for one of the ambiguous sentences and Figure 5, page 15 presents the averaged profile for one paragraph of the Alaska passage. Ideally, these profiles could be used to test hypotheses about various aspects of text processing. O'Regan, using eye movement data, has previously reported that the definite article "the" tends to be skipped during reading. That is, the word is fixated less than a three letter verb. A check of the Alaska passage showed that while the average height of the profile for the entire text was 35 msec., the average height over 21 definite articles was significantly lower, only 26 msecs. The Alaska passage also contained many dates and other numbers. As these tend to be important in historical texts it would seem that more processing time should be allocated. The average height of the profile over all dates and numbers was indeed higher, averaging 75 msecs. These effects, and the effects of lexical ambiguity, suggest that this approach may indeed be useful.

Clearly additional work is needed. Eye movement records must be collected from large numbers of subjects to determine the stability of profiles generated in this fashion. There are many issues in the study of reading and in cognitive psychology in general that are critically dependent upon notions of processing load. This type of analysis offers a way of using eye movement records to define the processing load at each and every position in a text, a task which is almost impossible with other types of measures.

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Table 1

Sample Materials From Ambiguity Study

Sergeant Jennings nailed the poster with the large letter "F" on it to the outside of the front door. It was important that all the new recruits see the letter as this would inform them that the rows of bunkbeds they would call home awaited them on the other side of the door. The sergeant briefly wondered whether the recruits would actually feel at home in the barracks, but quickly dismissed the thought form his mind. Certainly they would not miss the letter. At least that much seemed certain.

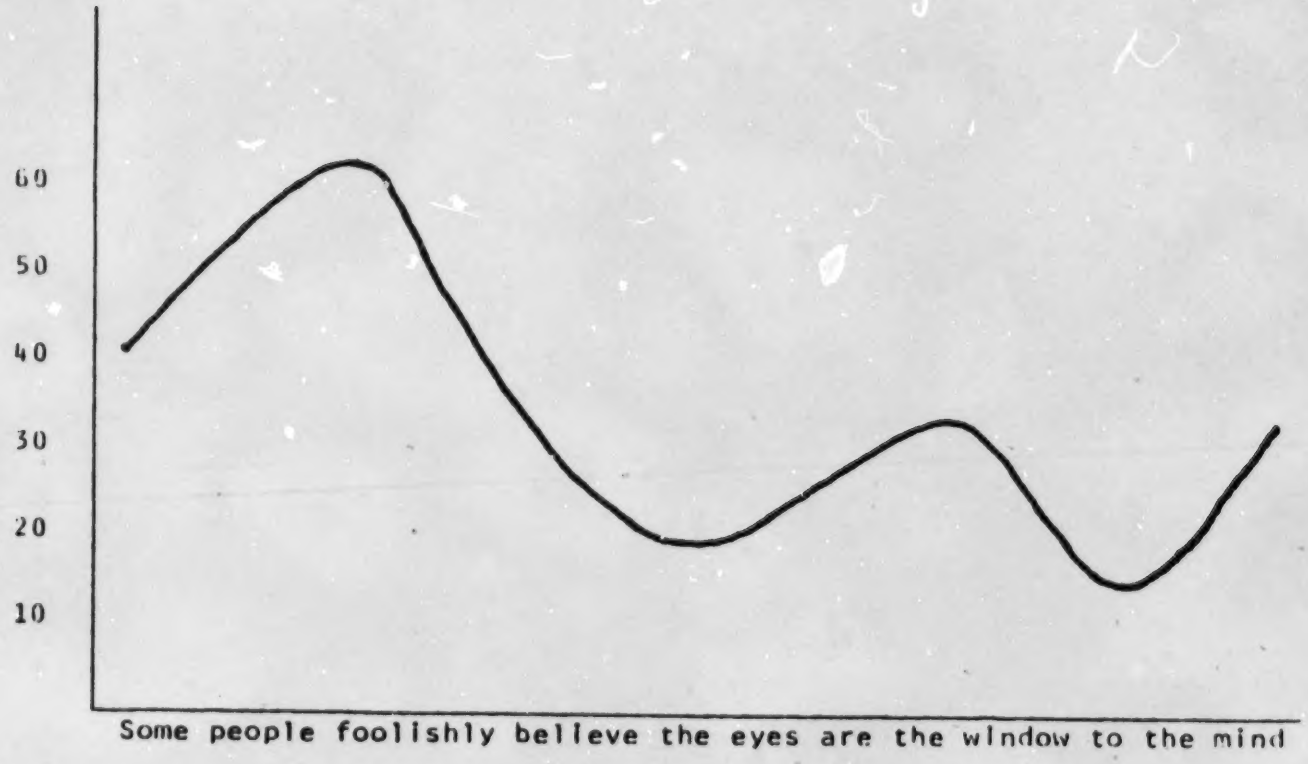


Figure 1. Hypothetical processing time profile.

Panel A

Some people foolishly believe the eyes are the window to the mind

1	2	3	4	5	6	7	8
238	150	398	405	250	475	129	163

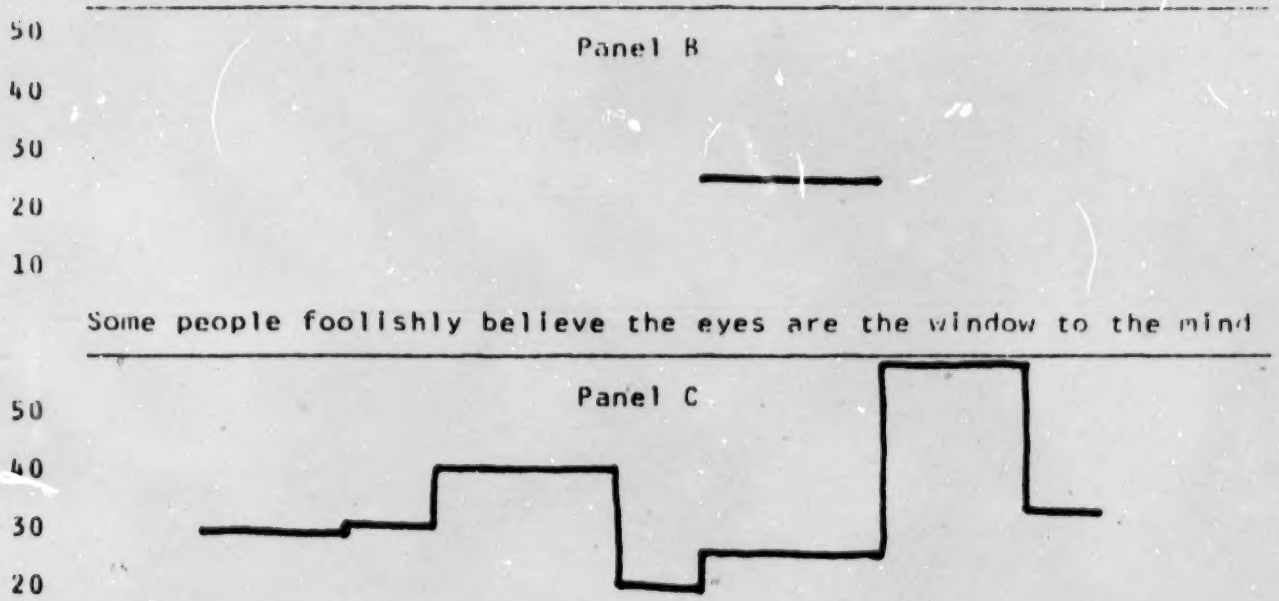
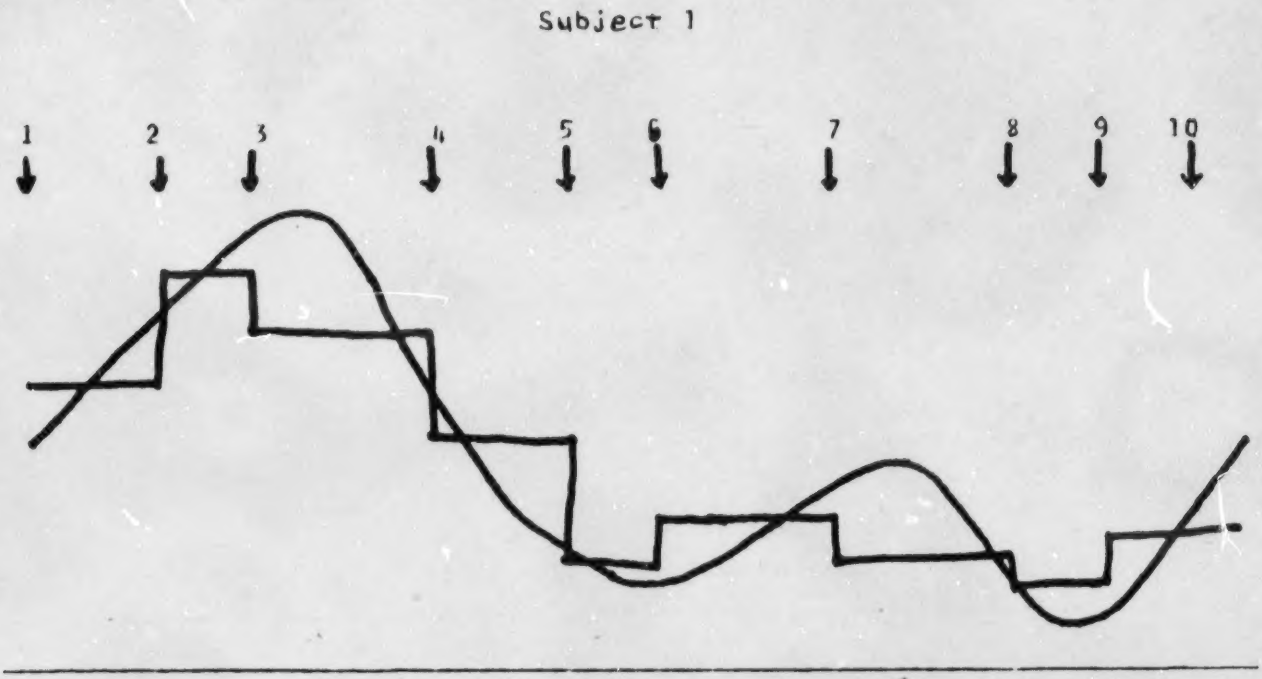


Figure 2. Step function profiles for hypothetical eye movement data.



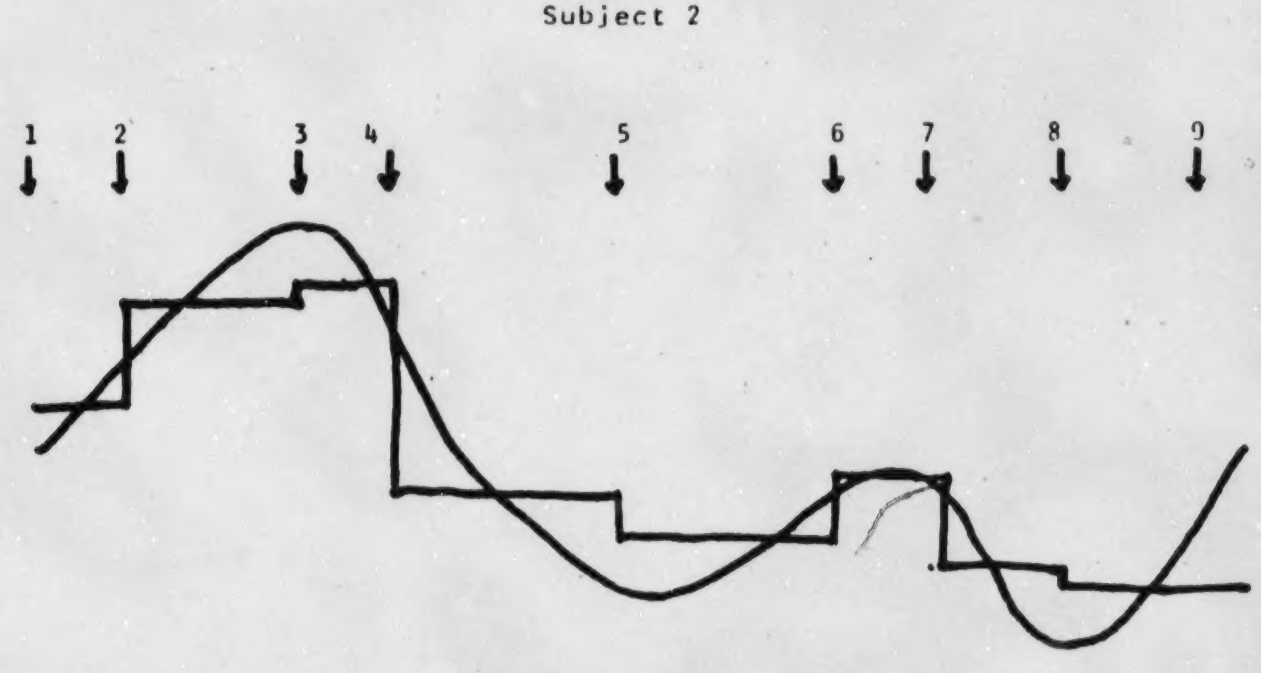
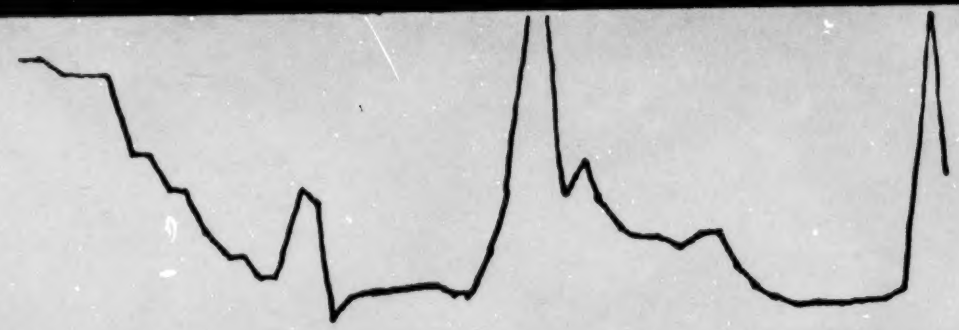
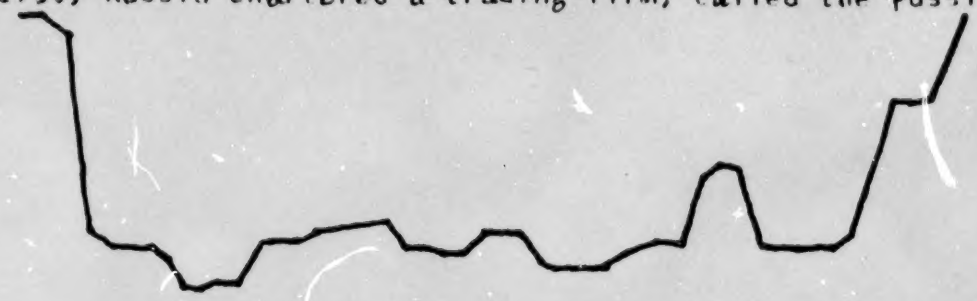


Figure 3. Comparison of profiles from two subjects.

Figure 4. Averaged profile for one sentence from ambiguity study.



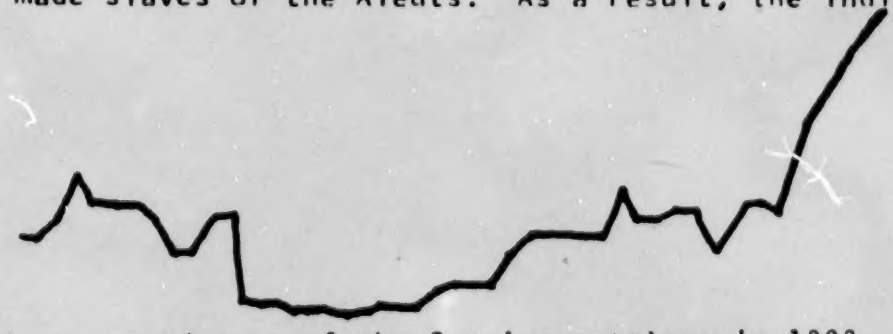
In 1799, Russia chartered a trading firm, called the Russian-



American Company. This company was the only governing power in

Alaska for the next 68 years. The company treated the Indians

harshly and made slaves of the Aleuts. As a result, the Indians



attacked and massacred many of the Russian settlers in 1802.

Figure 5. Averaged profile for one transect from Alaska passage